MYSTERY OF CALLISTO; William B. McKinnon, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130, 314-935-5604, mckinnon@wunder.wustl.edu

The Galileo Orbiter passed within ~1000 km of Callisto's surface last November. Analysis of the radio tracking by Anderson et al. [1], presented by Schubert et al. [2] at the December AGU, argued for a undifferentiated Callisto, consistent with this satellite's deathly appearance [3]. Assuming a perfect hydrostatic relationship between the second degree gravitational moments J_2 and C_{22}, they derived a reduced moment-of-inertia C/MR^2 of 0.406 ± 0.039, where 0.4 is the value for a uniform sphere. Their 1-σ lower limit of 0.367 allows for some differentiation; a simple two-layer model with ice above and mixed ice-rock below [1,2] gives an upper limit of ~300 km for the ice layer thickness, which [1,2] argue is *not* consistent with differentiation, because there would be plenty of unseparated ice in the rock-ice "core" in this model. A two layer model is not realistic, in the sense that separation of rock from ice should ultimately lead to formation of a rock core surrounded by a mixed ice-rock lower mantle and clean ice upper mantle [4,5]. Models of such partially differentiated Callistos [6] show that a 300-km ice layer corresponds to fully 50% differentiation and the formation of a rock core 1000 km in radius. This is a rather substantial degree of unmixing. So, is Callisto undifferentiated?

I have calculated new undifferentiated interior models for Callisto, using the ICYMOON code developed by S. Mueller and myself. This code can handle one-, two-, or three-layer icy satellites, for both fixed temperature layers and layers in which the temperature is self-consistently determined from the rock content and geologic age (through the heat flow), with either fixed or adiabatic interior temperature profiles. The radius and mass are taken from [7]. For an undifferentiated Callisto, I use both CI and PF-rock as plausible rock components [from 6], representing greater and lesser degrees of hydration and oxidation. A typical temperature profile through Callisto is conductive near the surface and then becomes adiabatic in the convective region, but the adiabatic temperature only varies modestly, between ~210 and 240, depending on the ice phase present. The adiabatic temperature at the top of the convecting region is determined here from the extremum hypothesis of Stevenson [e.g., 8, and see 9 for a discussion], based on the preferred Newtonian rheology in Table VI of [6].

As for typical density profiles, Callisto is significantly self-compressed due to the polymorphism of the ice phase. The density at the surface is ~1.4 g/cm^3 (rock + ice I) and increases to reach a maximum of ~2.2 g/cm^3 at the center (rock + ice VIII). The reduced moment-of-inertia, for either CI- or PF-rock based models, is 0.38, substantially lower than 0.4 and close to the lower limit of 0.367. Hence there is actually less leeway to accept a partially differentiated model, and the large moment-of-inertia [1,2] may appear to be something of an anomaly. Specifically, based on three-layer structural calculations, the lower limit of 0.367 restricts any ice upper mantle thickness to be <100 km, and the corresponding degree of differentiation to be <10% (I take the 1-σ limit at face value; obviously a 3-σ lower limit would admit any model, differentiated or undifferentiated). Even this level of differentiation is dubious, however, as the heat flows early in solar system history would have been high enough to cause the ice and ice-rock layers to convect separately. The thermal structure in such a three-layer model guarantees that the ice-rock layer is hotter and susceptible to further melting [6]; melting and differentiation should be self-sustaining to at least the pressure level of the ice III-V transition, and anything other than a trivial amount of differentiation (2%) would have been subject to this runaway melting [6].

It is possible for the derived reduced moment-of-inertia of a body to exceed 0.4, if there are unmodeled non-hydrostatic components of sufficient strength. I argued in [6] that contributions of J_2 of the order 10^{-5} were possible for an undifferentiated Callisto, due to uncompensated topography and density structure in the lithosphere. A contribution of half this amount could account for the excess in the nominal J_2 determined by [1,2], compared with the purely hydrostatic case. The implied stresses in Callisto's lithosphere are only a few percent of the kbar-level stresses supported by the lunar lithosphere [10], which is consistent with the long-term survival of 2–3 km of basin-generated topography on Callisto [11]. A much larger non-hydrostatic contribution by the core of a fully differentiated Callisto would be necessary to allow a differentiated Callisto to mimic an undifferentiated one (in terms of J_2 and C_{22}). While I argued in [6] that such might occur, the close to hydrostatic relationship between the J_2 and C_{22} (almost) independently determined for Ganymede [12] suggests that this is not likely

Finally I note that in terms of surface geology and remote sensing of Callisto, the density of primordial ice-rock is not the bulk density of the satellite, but a somewhat smaller value, ~1.4 g/cm^3, which yields a rock volume fraction at the surface of 0.2 (for PF-rock) to 0.275 (for CI-rock). The rock mass fraction for Callisto as a whole, expressed in anhydrous terms, is Å0.45 (for either assumed rock mineralogy), close to but still somewhat more rock-rich than theoretical predictions of the rock/ice mass ratio for equilibrium condensates in giant planet nebulae [9].

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REFERENCES: [1] Anderson, J.D., et al. (1997) *Nature*, submitted; [2] Schubert, G., et al. (1996) *EOS Trans. AGU*, *77*, F442; [3] Moore, J.M., et al. (1996) *EOS Trans. AGU*, *77*, F444; [4] Schubert, G., Stevenson, D.J., and Ellsworth, K. (1982) *Icarus*, *47*, 46-59; [5] McKinnon, W.B., and Parmentier, E.M. (1986) in *Satellites*, Univ. of Arizona Press, 718-763; [6] Mueller, S., and McKinnon, W.B. (1988) *Icarus*, *76*, 437-464; [7] Campbell, J.K., and Synnott, S. *Astron. J.*, *90*, 364-372; [8] Friedson, A.J., and Stevenson, D.J. (1983) *Icarus*, *56*, 1-14; [9] McKinnon, W.B., Simonelli, D.J., and Schubert, G. (1997) in *Pluto and Charon*, Univ. of Arizona Press, in press; [10] Solomon, S.C. (1986) *in Origin of the Moon*, LPI, Houston, 435-452; [11] Schenk, P.M., McKinnon, W.B., and Moore, J.M. (1997) *Lunar Planet. Sci. Conf. XXVIII*, these volumes; [12] Anderson, J.D., et al. (1997) *Nature*, *384*, 541-543.